US012131832B2

(12) **United States Patent**
Hebert

(10) **Patent No.: US 12,131,832 B2**
(45) **Date of Patent: Oct. 29, 2024**

(54) **MICROSPHERE CONTAINMENT SYSTEMS AND METHODS**

(71) Applicant: **Bard Peripheral Vascular, Inc.**, Tempe, AZ (US)

(72) Inventor: **Casey Tyler Hebert**, Tempe, AZ (US)

(73) Assignee: **Bard Peripheral Vascular, Inc.**, Tempe, AZ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 774 days.

(21) Appl. No.: **17/055,727**

(22) PCT Filed: **May 17, 2019**

(86) PCT No.: **PCT/US2019/032954**
§ 371 (c)(1),
(2) Date: **Nov. 16, 2020**

(87) PCT Pub. No.: **WO2019/222680**
PCT Pub. Date: **Nov. 21, 2019**

(65) **Prior Publication Data**

US 2021/0210239 A1 Jul. 8, 2021

Related U.S. Application Data

(60) Provisional application No. 62/673,632, filed on May 18, 2018, provisional application No. 62/673,628, filed on May 18, 2018.

(51) **Int. Cl.**
A61K 51/12 (2006.01)
A61M 5/31 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G21F 5/018*** (2013.01); ***A61K 51/1255*** (2013.01); ***A61M 5/3129*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC G21F 5/015; G21F 5/018; A61K 51/00; A61K 51/12; A61K 51/1241;
(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,313,440 A 2/1982 Ashley
5,478,323 A 12/1995 Westwood et al.
(Continued)

FOREIGN PATENT DOCUMENTS

DE 3035290 A1 4/1982
DE 4318101 A1 12/1994
(Continued)

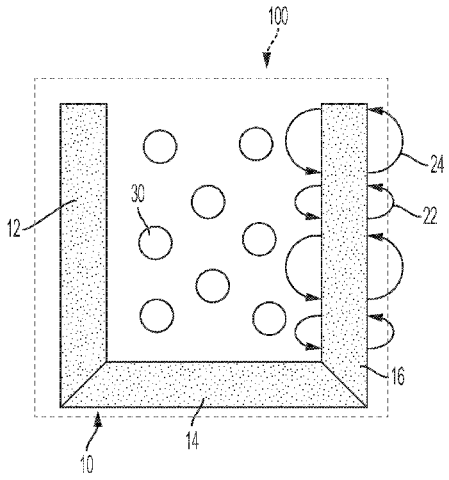
OTHER PUBLICATIONS

Chiesa, C. et al.; A dosimetric treatment planning strategy in radioembolization of hepatocarcinoma with 90Y glass microspheres; The Quarterly Journal of Nuclear Medicine and Molecular Imaging, vol. 56, No. 6; Dec. 1, 2012.
(Continued)

Primary Examiner — Eliza W Osenbaugh-Stewart
(74) *Attorney, Agent, or Firm* — Dinsmore & Shohl LLP

(57) **ABSTRACT**

In the present disclosure, embodiments of microbead containment systems and containment methods are disclosed. The microbead containment system may include a microsphere container, which includes walls that define a containment space in the microsphere container, and microspheres within the containment space. The walls may include at least one magnetic component configured to produce a magnetic field within the containment space. The microspheres may include a diamagnetic material. The method of containing radioactive microspheres may include loading a plurality of microspheres comprising a diamagnetic material in a container comprising one or more magnetic components. The microspheres contained in the micro-
(Continued)



sphere container interact with the magnetic field in a manner that prevents direct contact of the microspheres and the microsphere container.

17 Claims, 1 Drawing Sheet

(51) **Int. Cl.**

A61N 5/10	(2006.01)
G16H 20/17	(2018.01)
G16H 20/40	(2018.01)
G21F 5/018	(2006.01)
G21F 5/06	(2006.01)

(52) **U.S. Cl.**

CPC ***A61N 5/1001*** (2013.01); ***G16H 20/17*** (2018.01); ***G16H 20/40*** (2018.01); ***G21F 5/06*** (2013.01); *A61M 2205/0272* (2013.01); *A61N 2005/1019* (2013.01)

(58) **Field of Classification Search**

CPC A61K 51/1251; A61K 51/1255; A61M 5/1785; A61M 5/3129

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,496,284	A	3/1996	Waldenburg	
6,152,913	A	11/2000	Feith et al.	
6,159,271	A *	12/2000	Tillotson	B64G 1/402 96/155
6,508,807	B1	1/2003	Peters	
6,606,370	B1	8/2003	Kasprowicz	
6,723,074	B1	4/2004	Halseth	
7,713,239	B2	5/2010	Uber, III et al.	
2001/0021826	A1	9/2001	Winkler	
2003/0201639	A1	10/2003	Korkor	
2004/0111078	A1	6/2004	Miyahara	
2004/0258614	A1	12/2004	Line et al.	
2005/0085685	A1	4/2005	Barbut	
2006/0033334	A1	2/2006	Weber et al.	
2006/0091329	A1	5/2006	Eguchi	
2006/0293552	A1	12/2006	Polsinelli et al.	
2007/0129591	A1	6/2007	Yanke et al.	
2007/0141339	A1	6/2007	Song et al.	
2008/0058719	A1	3/2008	Edwards et al.	
2008/0103564	A1	5/2008	Burkinshaw et al.	
2008/0200747	A1	8/2008	Wagner et al.	
2009/0018498	A1	1/2009	Chiu et al.	
2009/0092677	A1	4/2009	Richard	
2009/0233586	A1	9/2009	Diodati et al.	
2010/0084585	A1	4/2010	Prosser	
2012/0190976	A1	7/2012	Kleinstreuer	
2012/0201726	A1	8/2012	Pearcy et al.	
2012/0289780	A1 *	11/2012	Farkas	A61B 5/6861 604/93.01
2013/0049187	A1	2/2013	Minamio	
2013/0165899	A1	6/2013	Haueter et al.	
2013/0317277	A1	11/2013	Lemer	
2014/0046295	A1	2/2014	Uber, III et al.	
2014/0163302	A1	6/2014	Fox et al.	
2014/0207178	A1	7/2014	Chomas et al.	
2014/0236093	A1	8/2014	Eggert et al.	
2014/0257233	A1	9/2014	Cowan	
2015/0273089	A1	10/2015	Gray	
2015/0285282	A1	10/2015	Weitz et al.	
2016/0325047	A1	11/2016	Vedrine et al.	
2016/0331853	A1	11/2016	Taub	
2016/0331998	A1	11/2016	Hoffman et al.	
2017/0065732	A1	3/2017	Srinivas et al.	
2017/0120032	A1	5/2017	Miyazaki et al.	
2017/0151357	A1	6/2017	Cade	
2017/0189569	A1	7/2017	Souresrafil et al.	
2017/0238951	A1	8/2017	Yang et al.	
2017/0304151	A1	10/2017	Van Den Berg et al.	
2018/0185040	A1	7/2018	Seip	
2018/0214707	A1 *	8/2018	Li	A61K 41/0052
2019/0338807	A1 *	11/2019	Willmot	B64G 1/50

FOREIGN PATENT DOCUMENTS

EP	2179758	A2	4/2010
FR	2917981	A1	1/2009
JP	2006017660	A	1/2006
JP	2010068603	A	3/2010
JP	2013071082	A	4/2013
WO	2007008511	A2	1/2007
WO	2009039203	A2	3/2009
WO	2011014562	A1	2/2011
WO	2012006555	A1	1/2012
WO	2012118687	A1	9/2012
WO	2013153722	A1	10/2013
WO	2014165058	A1	10/2014
WO	2016049685	A1	4/2016
WO	2016161346	A1	10/2016
WO	2017053398	A1	3/2017
WO	2017157974	A1	9/2017
WO	2019006099	A1	1/2019
WO	2019222699	A1	1/2019
WO	2019222687	A1	11/2019
WO	2019222700	A1	11/2019
WO	2019222713	A1	11/2019

OTHER PUBLICATIONS

Chiesa, C. et al.; Radioembolization of hepatocarcinoma with 90Y glass microspheres: development of an individualized treatment planning strategy based on dosimetry and radiobiology; European Journal of Nuclear Medicine and Molecular Imaging, Springer Verlag, Heidelberg, DE; vol. 42; No. 11; Jun. 27, 2015.

Spreafico, C. et al.; The dosimetric importance of the number of 90Y microspheres in liver transarterial radioembolizaiton (TARE); European Journal of Nuclear Medicine and Molecular Imaging, Springer Verlag, Heidelberg, DE; vol. 41, No. 4; Jan. 30, 2014.

International Search Report and Written Opinion dated Aug. 1, 2019 pertaining to International Application No. PCT/US2019/032983.

International Search Report and Written Opinion dated Dec. 13, 2019 pertaining to International Application No. PCT/US2019/032987.

International Search Report and Written Opinion dated Oct. 16, 2019 pertaining to International Application No. PCT/US2019/032955.

International Search Report and Written Opinion dated Jul. 23, 2019 pertaining to International Application No. PCT/US2019/032950.

International Search Report and Written Opinion dated Sep. 24, 2019 pertaining to International Application No. PCT/US2019/033011.

International Search Report and Written Opinion dated Jul. 26, 2019 pertaining to International Application No. PCT/US2019/032965.

International Search Report and Written Opinion dated Jul. 29, 2019 pertaining to International Application No. PCT/US2019/032954.

International Search Report and Written Opinion dated Aug. 7, 2019 pertaining to International Application No. PCT/US2019/032986.

Arepally, A.; Quantification and Reduction of Reflux during Embolotherapy Using an Antireflux Catheter and Tantalum Microspheres: Ex Vivo Analysis; J Vasc Interv Radiol; 2013; 24:575-580.

Chung, J. et al.; Novel use of the Surefire antireflux device in subtotal splenic embolization; Journal of Vascular Surgery Cases; Dec. 1, 2015; pp. 242-245; vol. 1, No. 4.

Ho, S. et al; Clinical evaluation of the partition model for estimating radiation doses from yttrium-90 microspheres in the treatment of hepatic cancer; European Journal of Nuclear Medicine, Springer, Berlin, Heidelberg, DE: vol. 24. No. 3; Mar. 1, 1997.

Hospital Clinics et al.; Y-90 MicroSpheres (SIRSpheres) for treatment of hepatocellular carcinoma; Mar. 1, 2017.

(56) **References Cited**

OTHER PUBLICATIONS

Morshedi, M. et al.; Yttrium-90 Resin Microsphere Radioembolization Using an Antireflux Catheter: An Alternative to Traditional Coil Embolization for Nontarget Protection; Cardiovasc Intervent Radiol; 2015; 38:381-38; Springer.

Sirtex Medical Limited: Sirtex Medical Products Pty Ltd SIR-Spheres (Ytttrium-90 Microspheres); Apr. 1, 2005.

Theragenics Corp.; Therasphere IDOC TM; Aug. 4, 2015.

Tong, A. et al; Yttrium-90 hepatic radioembolization: clinical review and current techniques in interventional radiology and personalized dosimetry; British Journal of Radiology; vol. 89, No. 1062; Jun. 1, 2016.

US FDA; Theresphere IDOC—Humanitarian Device Exemption (HDE); Sep. 14, 2015.

Westcott, M. et al.; The development, commercialization, and clinical context of yttrium-90 radiolabeled resin and glass microspheres; Advances in Radiation Oncology; 2016; vol. 1; pp. 351-364.

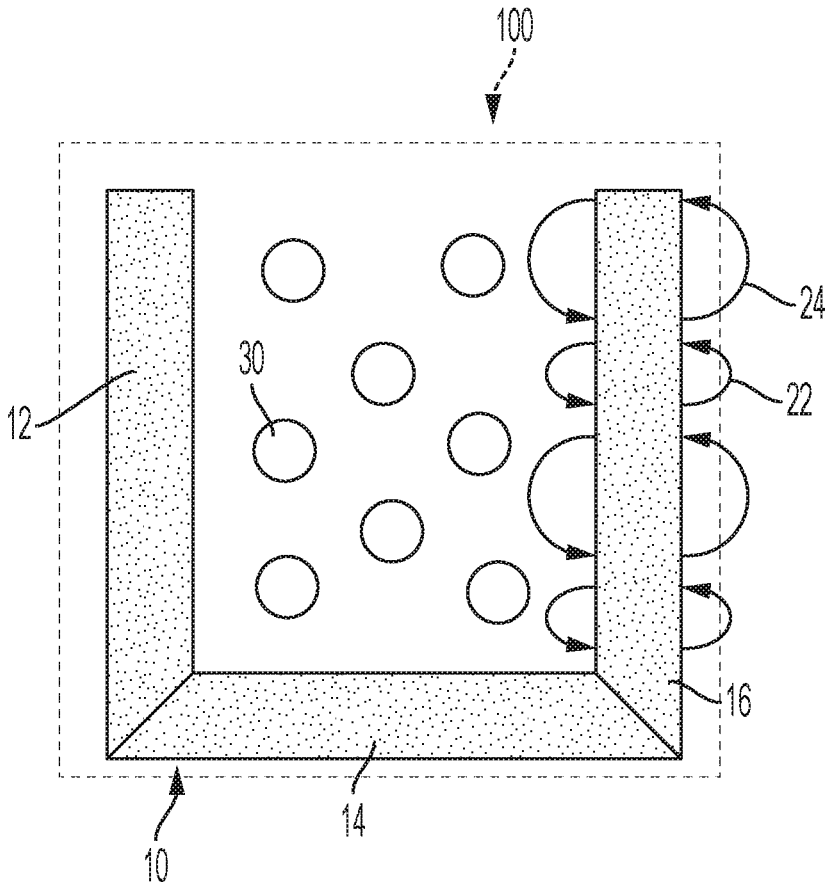
Sirtex Medical Limited; SMAC-SIR-Spheres Microspheres Activity Calculator; May 6, 2018.

Office Action dated Feb. 17, 2023 pertaining to JP Patent Application 2020-564535.

NZ Examination Report dated Nov. 9, 2024 pertaining to NZ application No. 770700.

Australian Examination Report dated Mar. 26, 2024 pertaining to AU application No. 2019270182 filed Dec. 3, 2020.

* cited by examiner


100
24
30
22
12
16
14
10

MICROSPHERE CONTAINMENT SYSTEMS AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a National Stage Entry under 35 U.S.C. § 371 of International Patent Application No. PCT/US2019/032954, entitled "MICROSPHERE CONTAINMENT SYSTEMS AND METHODS", filed May 17, 2019, which claims the benefit of priority to U.S. Provisional App. No. 62/673,632, entitled "RADIOEMBOLIZATION DELIVERY DEVICE" filed May 18, 2018, the disclosure of which is incorporated by reference herein; and to U.S. Provisional App. No. 62/673,628, entitled "DUAL-STAGE SYRINGES WITH LOCKING MECHANISM" filed May 18, 2018, the disclosure of which is incorporated by reference herein.

TECHNICAL FIELD

The present disclosure relates generally to containment systems for radioactive or volatile substances and, more particularly, to containment systems for particles that include radioactive or volatile substances.

BACKGROUND

In radiation physics, the amount of radiation deposited in a certain amount (mass) of tissue or other solid object is referred to as an absorbed dose. The unit for absorbed dose is the gray (Gy). Absorbed dose is proportional to the inverse square of the distance (R) from the tissue to the radioactive source, such as a radioactive microbead (i.e. dose=$1/R^2$). For example, for every doubling of distance from the radioactive source, the absorbed dose decreases to one fourth the amount from the original distance.

Microspheres utilized for radioembolization medical treatment may emit a dose of radiation to materials and tissues surrounding the microbead materials. When such microspheres are in a stored container such as a glass vial, the microspheres can settle out of solution and directly contact the container (i.e., R=0). If the radioactive microspheres remain in that position for an extended period of time (for example, greater than 1 week), the container may experience an absorbed dose of approximately 5,000 kGy, which is equivalent to approximately 150 gamma sterilization cycles. Depending on the material of container, the absorbed dose may cause the container to become brittle, cracked, flaked, discolored, or otherwise integrity compromised.

SUMMARY

Microspheres utilized for radioembolization treatments may conventionally be stored in containers, such as glass vials, for weeks at a time. Therefore, such containers used to store radioactive microspheres for radioembolization may absorb greater than 5,000 kGy of radiation dose. Despite browning and embrittlement under such circumstances, glass vials remain an industry standard for storage of radioactive materials. However, the manufacture of glass containers is more costly than the manufacture of plastic containers.

Another challenge of storing and administering radioembolization microspheres concerns the potential for the microspheres to cling to the container or to delivery lines as a result of static electricity, lubricants used, the microspheres' geometry, or the container's geometry. In the case of radioembolization microspheres, residual microspheres that cling to the vials and delivery lines pose a risk to physicians. Moreover, the residual microspheres may result in misadministration.

Therefore, ongoing needs exist for containment systems for the storage of microspheres used for radioembolization, which include materials that may reduce interaction or binding of the microspheres with the container and browning or embrittlement of the container.

The proposed containment systems meet the foregoing needs by incorporating the principles of diamagnetism. Most nonferrous materials, such as graphite and bismuth, naturally repel from magnetic poles. By adjusting the power of the magnetic field, a plurality of microspheres that include diamagnetic materials may be repelled or "levitated" at a certain distance from one or more magnetic surfaces of a container.

Accordingly, example embodiments disclosed herein are directed to containment systems for use in medical settings where microspheres or particles containing hazardous or volatile substances are stored and subsequently administered, such as radioembolization microspheres. The presently disclosed containment systems may reduce interaction or binding of such microspheres with the containers when compared to conventional containers, such as syringes and vials, currently used in radioembolization treatment. Additionally, in some embodiments, non-uniform magnetic fields along the vessel may facilitate the mixing of the microspheres in the suspension medium.

According to at least one embodiment of the present disclosure, a microbead containment system is provided. A microsphere containment system for storing microspheres including a diamagnetic material may include a microsphere container comprising walls that define a containment space in the microsphere container, the walls comprising at least one magnetic component configured to produce a magnetic field within the containment space. The microspheres including a diamagnetic material, when stored within the containment space, may interact with the magnetic field within the containment space in a manner that prevents direct contact between of the microspheres and with the walls of the microsphere container.

According to at least one embodiment of the present disclosure, a microbead containment method is provided. The method may include loading microspheres comprising a diamagnetic material into a microsphere container comprising walls that define a containment space in the microsphere container. The walls may include at least one magnetic component configured to produce a magnetic field within the containment space. The microspheres in the microsphere container may interact with the magnetic field in a manner that prevents direct contact of the microspheres to the container.

These and other features, aspects, and advantages of the present disclosure will become better understood with reference to the following description and the appended claims.

Additional features and advantages of the embodiments described herein will be set forth in the detailed description that follows, and in part will be readily apparent to those skilled in the art from that description or recognized by practicing the embodiments described herein, including the detailed description that follows, the claims, as well as the appended drawings.

It is to be understood that both the foregoing general description and the following detailed description describe various embodiments and are intended to provide an over-

view or framework for understanding the nature and character of the claimed subject matter. The accompanying drawings are included to provide a further understanding of the various embodiments, and are incorporated into and constitute a part of this specification. The drawings illustrate the various embodiments described herein, and together with the description serve to explain the principles and operations of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an illustration of a microbead containment system according to embodiments.

DETAILED DESCRIPTION

Specific embodiments of the present application will now be described. These embodiments are provided so that this disclosure will be thorough and complete and will fully convey the scope of the subject matter to those skilled in the art.

Reference will now be made in detail to embodiments of microbead containment systems. The microbead containment systems described herein may include a plurality of microspheres comprising a diamagnetic material and a container comprising one or more magnetic walls. In embodiments, the walls of the container may include one or more magnetic components, which may influence the distribution or behavior of the plurality of microspheres within the container. As subsequently described in more detail, the one or more magnetic walls may produce a magnetic field that repels the diamagnetic material of the plurality of microspheres. This repulsion between the magnetic walls and the diamagnetic material of the beads may cause the plurality of microspheres to levitate within the container.

Referring now to FIG. **1**, a section view of an embodiment of a microbead containment system **100** is provided. In FIG. **1**, the microbead containment system **100** may include a container **10**, formed by walls **12**, **14**, **16**. The container **10** may contain a plurality of microspheres **30**. Additionally, the walls **12**, **14**, **16** of the container **10** may produce one or more magnetic fields of varying sizes, illustrated as greater magnetic fields **24** and lesser magnetic fields **22**.

Reference will now be made in detail to embodiments of the container **10**. The container **10** may be any barrel, vessel, box, vial, receptacle, or tank that defines a containment space and is suitable for storing the plurality of microspheres **30** previously described herein. In some specific embodiments, the container **10** may be a syringe barrel. In the exemplary embodiment depicted in the section view of FIG. **1**, the container **10** may be a box with a base wall and four side walls. In the section view shown in FIG. **1**, the container **10** includes a base wall **14** and side walls **12** and **16**. The container may also include front walls and back walls not shown in FIG. **1**. In other embodiments, the container may include walls of any shape, including walls that are rounded, cylindrical, or angled, for example, provided the walls form a container suitable for containing the plurality of microspheres **30**. In some embodiments, the container may include a lid, a top wall, septum or other solid feature that seals the plurality of microspheres within the container **10**.

The container **10** may be made from any suitable gamma compatible material. A gamma compatible material may be any radiation-stable, medical-grade polymer material, such as those provided subsequently in Table 1.

TABLE 1

Gamma Compatible Materials	
MATERIAL	TOLERANCE LEVEL (KGY)
Thermoplastics	
Acrylonitrile/Butadiene/Styrene (ABS)	1,000
Aromatic Polyesters (PET, PETG)	1,000
Cellulosics	
Esters and Ethers	100
Paper, Card, Corrugated, Fibers	100-200
Cellulose Acetate Propiconate and Butyrate	100
Fluoropolymers	
Tetrafluroethylene (PTFE)	5
Polychlorotrifluoroethylene (ECTFE)	200
Polyvinyl Fluoride	1,000
Polyvinylidene Fluoride (PVDF)	1,000
Ethylene-Tetrafluoroethylene (ETFE)	1,000
Fluorinated Ethylene Propylene (FEP)	50
Polyacetals (Delrin, Celcon)	5
Polyacrylics	
Polymethylmethacrylate	100
Polyacrylonitrile	100
Polyacrylate	100
Polycyanoacrylate	200
Polyamides (Nylons)	
Aliphatic & Amorphous Grades	50
Aromatic Polyamide/Polyimide	10,000
Polycarbonate	1,000
Polyethylene (LDPE, LLDPE, HDPE, UHMPE, UHMWPE)	1,000
Polyimides	10,000
Polymethylpentene	20
Polyphenylene Sulfide	1,000

TABLE 1-continued

Gamma Compatible Materials	
MATERIAL	TOLERANCE LEVEL (KGY)
Polypropylene, Radiation Stabilized	20-50
Homopolymer	20-50
Copolymers of Propylene-Ethylene	25-60
Polypropylene, natural	20
Polystyrene	10,000
Polysulfone	10,000
Polyurethane	10,000
Polyvinylbutyral	100
Polyvinylchloride (PVC)	100
Polyvinylidene Chloride (PVDC)	100
Styrene/Acrylonitrile (SAN)	1,000
Thermosets	
Allyl Digylcol Carbonate (Polyester)	5,000-10,000
Epoxies	1,000
Phenolics	50,000
Polyesters	100,000
Polyurethanes	100-1,000
Elastomers	
Butyl	50
Ethylene-Propylene Diene Monomer (EPDM)	100-200
Fluoro Elastomer	50
Natural Rubber (Isoprene)	100
Nitrile	200
Polyacrylic	50-200
Polychloroprene (Neoprene)	200
Silicones (Peroxide & Platinum Catalyst systems)	50-100
Styrene-Butadiene	100
Urethanes	100-200

The radiation stability of the gamma compatible material may be dependent on the tolerance level of the particular type of medical grade polymer material. Once the container material absorbs a radiation dose that exceeds the container material's tolerance level, browning or embrittlement of the container **10** may occur. Exemplary gamma compatible materials include, but are not limited to, thermoplastics, including acrylonitrile/butadiene/styrene, aromatic polyesters, cellulosics, fluoropolymers, polyacetals, polyacrylics, polyamides, polyethylenes polyimides, polymethylpentene, polyphenylene sulfide, polypropylenes, polystyrenes, polysulfones, polyurethanes, polyvinylbutyral, polyvinylchloride, polyvinylidene chloride, styrene/acrylonitrile; thermosets including allyl digylcol carbonate, epoxies, phenolics, polyesters, polyurethanes, and elastomers including butyl, ethylene-propylene diene monomer, fluoro elastomers, natural rubbers, nitriles, polyacrylics, polychloroprenes, silicones, styrene-butadienes, and urethanes. The radiation tolerance of the elastomers may be affected by the base polymer and the curing system used. In some embodiments, the container **10** may be made from a gamma compatible material with a tolerance level of from about 5 kGy to about 100,000 kGy, from about 5 kGy to about 10,000 kGy, from about 5 kGy to about 5,000 kGy, from about 5 kGy to about 1,000 kGy, from about 5 kGy to about 500 kGy, from about 5 kGy to about 100 kGy, from about 100 kGy to about 100,000 kGy, from about 100 kGy to about 10,000 kGy, from about 100 kGy to about 5,000 kGy, from about 100 kGy to about 1,000 kGy, from about 100 kGy to about 500 kGy, from about 500 kGy to about 100,000 kGy, from about 500 kGy to about 10,000 kGy, from about 500 kGy to about 5,000 kGy, from about 500 kGy to about 1,000 kGy, from about 1,000 kGy to about 100,000 kGy, from about 1,000 kGy to about 10,000 kGy, from about 1,000 kGy to about 5,000 kGy, from about 5,000 kGy to about 100,000 kGy, from about 5,000 kGy to about 10,000 kGy, or from about 10,000 kGy to about 100,000 kGy.

In embodiments, the walls of the container **10** may include one or more magnetic fields. The one or more magnetic fields of the container **10** may interact with the plurality of microspheres **30** in a manner that prevents direct contact of the plurality of microspheres to the container. In some embodiments, the one or more magnetic fields of the container **10** may interact with the plurality of microspheres **30** in a manner that facilitates mixing of the plurality of microbeads. The mixing may, at least in part, be facilitated by the shape of the walls of the container **10**. In embodiments, the strength, location, and pattern of the one or more magnetic fields of the container **10** may vary. The magnetic fields may be of sufficient magnitude to levitate or repel the plurality of microspheres **30** off the surface of the container **10**. This magnitude may be depend on various factors, including the radiation tolerance of the container material; the amount of therapeutic agent in the microsphere, more specifically, the amount of radiotherapeutic material in the microsphere; the type of therapeutic agent in the microsphere, more specifically, the amount of radiotherapeutic material in the microsphere; the amount (mass) of microsphere material, the type of microsphere material, the amount (mass) of diamagnetic material, the type of diamagnetic material, and combinations of these factors. The magnetic fields may be of sufficient magnitude to levitate or repel the plurality of microspheres at a height sufficient to prevent browning or embrittlement of the container **10**. Without being bound by theory, because the dose is reduced by $1/R^2$, relatively small changes in distance can have a substantial impact on the dose absorbed by the container **10**.

In some embodiments, the container **10** may include multiple magnetic fields. In further embodiments, the con-

tainer **10** may include multiple magnetic fields of varying strengths (e.g. multiple zones having varying magnitudes of magnetic field strength). For example, at least a portion of the magnetic fields of the container **10** may be of a lesser strength **24**, and at least a portion of the magnetic fields of the container **10** may be of a greater strength **24**. The varying strengths of the magnetic fields of the container **10** may facilitate mixing of the plurality of microspheres **30** within the container **10**.

In embodiments, the magnetic fields of the container **10** may be produced by incorporating one or more magnetic components into the walls of the container **10**. In other embodiments, the magnetic fields of the container **10** may be produced by surrounding the container **10** with one or more magnetic components. When the walls of the containers described herein comprise one or more magnetic components, the walls may comprise any number of individual magnetic components (e.g., one, two, three, four, five, six, seven, or eight or more, etc.). Each magnetic component may be fixed in or on the container **10** by any suitable method. For example, in some variations one or more magnetic components may be embedded in, adhered to, or friction-fit within the container **10** by any suitable manufacturing methods, including by painting, over-molding, printing, or gluing the one or more magnetic components onto the container **10**. In embodiments where one or more magnetic components surround the container **10**, each magnetic component may not be fixed in or on the container **10**, so the magnetic fields produced by the magnetic components may be mobile. In further embodiments where one or more magnetic components surround the container **10**, each magnetic component may be embedded in, adhered to, or friction-fit within a casing, cover, or other external component that surrounds at least a portion of the container **10**.

In embodiments, the magnetic component may include a permanent magnet. The magnet may be made of any suitable material capable of generating a magnetic field. In some embodiments, the magnetic components may be permanent magnets made out of ferromagnetic materials. For example, in some variations, the magnetic components may comprise one or more rare-earth magnets, cobalt, gadolinium, iron, nickel, alloys of these metals with or without other metals such as alnico, chemical compounds such as ferrites, or a combination of any of these metals or their alloys. In further embodiments, the rare-earth magnets may include samarium cobalt magnets or neodymium magnets.

In embodiments, the magnetic component may include an electromagnet. When a magnetic component comprises an electromagnet, the electromagnet may be selectively activated to produce a magnetic field. For example, when one or more container walls of the systems described here comprise one or more electromagnets, the electromagnets may be activated before the plurality of microspheres **30** are loaded in the container; the electromagnets may remain activated during storage of the plurality of microspheres **30** to levitate the plurality of microspheres **30** and keep them from settling in the container **10**; and then the electromagnets may be deactivated after the plurality of microspheres **30** are removed from the container or after the radioembolization procedure is complete. When the container comprises multiple electromagnets, these magnetic components may be independently activated or may be activated as a group. In embodiments, the one or more electromagnets may be selectively activated by an electronic interaction, such as by a battery and a switch or other suitable activating means. In some embodiments, the one or more electromagnets may be selectively activated in a manner to create one or more pulsating magnetic fields. In further embodiments, multiple electromagnets may be selectively activated in a manner to create multiple pulsating magnetic fields with varying magnitudes.

In embodiments, the container may include multiple magnetic components. In further embodiments, the multiple magnetic components may be any combination of permanent magnets, ferromagnetic components, or electromagnets. In one exemplary embodiment, only the side walls (i.e., the side wall **12**, the side wall **16**, the front wall not shown in FIG. **1**, and the back wall not shown in FIG. **1**) of the container **10** may include permanent magnets. In these variations, the base wall **14** may include only permanent magnets, only ferromagnetic components, only electromagnets, or a mix of some or all of these elements. In the side walls of the container **10** may include permanent magnets, and the base wall **14** or a lid may include only electromagnets that may be activated after the plurality of microspheres **30** have been loaded into the container **10**.

In embodiments, each magnetic component may have any suitable size and shape. For example, each magnetic component may be cylindrical, semi-cylindrical, tube-shaped, box-shaped, planar, spherical, or the like. Generally, the dimensions of the magnetic components may be constrained by size of the containers carrying the magnetic components, which in turn may be constrained by the radioembolization procedure itself. For example, the radioembolization procedure may require a specific dose or delivery device, in which case, the container **10** may be specifically sized to accommodate said dose or fit within said delivery device. Each magnetic component may have any suitable length. In some embodiments, each magnetic component may have a length of about 5 mm, about 10 mm, about 15 mm, about 20 mm, or each magnetic component may extend along the entire length of one wall of the container **10**.

Reference will now be made in detail to embodiments of the plurality of microspheres **30**. The plurality of microspheres **30** may include multiple microspheres, which may be regularly or irregularly shaped, which may also be referred to as a "microbeads." In some embodiments, the plurality of microspheres may alternatively include a plurality of particles, which may be regularly or irregularly shaped, or a plurality of flakes, which may be regularly or irregularly shaped. In other embodiments, the plurality of microspheres **30** may include a combination of microspheres, particles, and/or flakes. In other embodiments, the plurality of microspheres **30** may include one or more composite particle that includes a conglomerate of microspheres, particles, flakes, or combinations. In embodiments, the plurality of microspheres **30** may include any microspheres suitable for use in embolization treatment procedures, such as microspheres used as scout beads or microspheres used for therapeutic treatment. In embodiments of the microbead containment system **100** described herein, the plurality of microspheres **30** includes microspheres that comprise a diamagnetic material or a therapeutic agent. In further embodiments, the plurality of microspheres **30** includes microspheres that comprise a diamagnetic material and a therapeutic agent. In further embodiments, the plurality of microspheres **30** includes microspheres that comprise a diamagnetic material and a therapeutic agent and a microbead material. In some embodiments, each microbead in the plurality of microspheres **30** may include the diamagnetic material, the therapeutic agent, and the microbead material. In some embodiments, only some of the microspheres in the plurality of microspheres **30** may include the diamagnetic

material, the therapeutic agent, or a combination of the diamagnetic material and the therapeutic agent.

Individual microspheres of the plurality of microspheres **30** may have diameters of a size suitable radioembolization medical treatment. In some embodiments, individual microspheres of the plurality of microspheres **30** may have diameters of about 30 micrometers (μm) to about 1500 μm. In other embodiments, the individual microspheres of the plurality of microspheres **30** may have diameters of about 30 μm to about 1500 μm, about 30 μm to about 1000 μm, about 30 μm to about 500 μm, about 30 μm to about 100 μm, about 100 μm to about 1500 μm, about 100 μm to about 1000 μm, about 100 μm to about 500 μm, about 500 μm to about 1500 μm, about 500 μm to about 1000 μm, or about 1000 μm to about 1500 μm.

The microspheres of the plurality of microspheres **30** may include a microbead material. In some embodiments, the microbead material may include glass or silica. In other embodiments, the microbead material may include biodegradable and bioresorbable materials, which are materials that degrade and/or are reabsorbed safely within the body. Examples of biodegradable and bioresorbable materials may include, without limitation, polyglycolic acid (PGA), polyhydroxy butyrate (PHB), polyhydroxy butyrates-co-beta hydroxyl valerate (PHBV), polycaprolactone (PCL), Nylon-2-nylon-6, polylactic-polyglycolic acid copolymers, PLGA-polyethylene glycol (PEG)-PLGA (PLGA-PEG-PLGA), carboxymethylcellulose-chitosan (CMC-CCN), chitosan, hydroxyethyl acrylate (HEA), iron-based alloys, magnesium-based alloys, and combinations thereof. In other embodiments, the microbead material may be a polymer material. In further embodiments, the microbead material may be a water-swellable polymer material, such as a polymer material capable of forming a hydrogel. The microspheres of the plurality of microspheres **30** may have any shape common to microparticles formed from microbead material, or more specifically, a hydrogel type water-swellable polymer material. For example, the microspheres of the plurality of microspheres **30** may be spherical or substantially spherical, may have an ovoid shape with oval-shaped or elliptical cross-sections about a longitudinal axis and circular cross-sections about an axis perpendicular to the longitudinal axis, or combinations thereof. In some embodiments, the microspheres may be porous.

In various embodiments, the microbead material may include water-swellable polymer material that includes a natural hydrogel polymer such as a chitosan or a polysaccharide, or a synthetic hydrogel polymer such as a polyacrylate, a polyamide, a polyester, a polysaccharide, a poly (methylmethacrylate), or a poly(vinyl alcohol), for example. In some embodiments, the water-swellable polymer material may be biodegradable. Specific examples of water-swellable polymer materials include, without limitation, poly(4-hydroxybutyrate), methacrylated hyaluronic acids (hyaluronic acids being polymers of disaccharides composed of D-glucuronic acid and N-acetyl-D-glucosamine), chitosan-alginates, poly(N-isopropylacrylamide) copolymers, poly(N-isopropylacrylamide)-alginates, poly(N-isopropylacrylamide)-peptides, poly(N-isopropylacrylamide)-α-acryloyloxy-β,β-dimethyl-γ-butyrolactone-hydrophilic Jeffamine, or poly(N-isopropylacrylamide)-poly(ethylene glycol) diacrylate-pentaerythritol tetrakis(3-mercapto-propionate). The microbead material may include may include water-swellable polymer materials that include derivatives of any of the foregoing materials, or may include combinations of any of the foregoing materials or their derivatives. For example, the microbead material may include a combination of multiple water-swellable polymer materials, in which each individual microbead is made of a single type of polymer, and the plurality of microspheres **30** includes microbead materials of multiple polymer types. In some embodiments, the microbead material may include a combination of multiple water-swellable polymer materials, in which individual microspheres are composed of multiple types of polymer.

In embodiments, the individual microspheres of the plurality of microspheres **30** may include from about 30% by weight to about 70% by weight, or from about 35% by weight to about 65% by weight, or from about 40% to about 60% by weight, or about 45% by weight to about 55% by weight, or about 50% to about 70% by weight microbead material, based on the total weight of the individual microspheres. In further embodiments, individual microspheres of the plurality of microspheres **30** may include from about 30% by weight to about 70% by weight, or from about 35% by weight to about 65% by weight, or from about 40% to about 60% by weight, or about 45% by weight to about 55% by weight, or about 50% to about 70% by weight water-swellable polymer material, based on the total weight of the individual microspheres in the plurality of microspheres **30**.

As stated previously, the plurality of microspheres **30** may include one or more diamagnetic materials. In particular, a diamagnetic material is a material that is repelled by both poles of a dipole magnet. When a diamagnetic material is placed within an external magnetic field, the magnetic fields created by the electrons of diamagnetic material point in a direction opposite that of the external magnetic field. Because opposing magnetic fields naturally repel each other, this interaction results in a repulsive force.

Therefore, in embodiments, the plurality of microspheres **30** may include one or more diamagnetic materials, which may exhibit magnetic repulsion to the external magnetic field produced by the magnetic container walls **12**, **14**, **16**, thereby allowing the plurality of microspheres **30** to move according to the magnetic repulsion. In some embodiments, the one or more diamagnetic materials of the plurality of microspheres **30** may exhibit electromagnetic repulsion to an applied electrical current, an electrical field, or both, which thereby allows the plurality of microspheres **30** to move according to the electromagnetic repulsion. In a non-limiting example, the plurality of microspheres **30** may move away from the container **10** when the plurality of microspheres **30** comprise one or more diamagnetic materials that are magnetically or electromagnetically repelled from the container walls **12**, **14**, and **16**.

Illustrative materials that react to an electrical current or electrical field may include, but are not limited to, metals, electrolytes, superconductors, semiconductors, nonmetallic conductors, conductive polymers, shape memory polymers, and shape memory alloys. In embodiments, illustrative diamagnetic materials may include, but are not limited to, water, wood; glass; ceramics; carbon, graphite; organic compounds such as petroleum, plastic, biological tissue; and metals such as copper, mercury, gold, and bismuth. In some embodiments, the one or more microspheres may include one or more of glass, ceramics, carbon, graphite, metals, or combinations thereof. In some specific embodiments, the one or more microspheres may include one or more of graphite, bismuth, or combinations thereof, which may be selected for economical benefits during the manufacturing process or for performance benefits.

In the microspheres of the plurality of microspheres **30**, the one or more diamagnetic materials may be generally surrounded by the microbead material. In some embodi-

ments, the water-swellable polymer material or some portion thereof may generally surround the one or more diamagnetic materials. In other embodiments, a microbead material shell, such as a water-soluble polymer material shell, may encapsulate a core that holds the one or more diamagnetic materials. In other embodiments, the one or more diamagnetic materials may be physically disposed within a matrix, network, or pore structure of the microbead material that may or may not have a core within an outer shell. In other embodiments, the one or more diamagnetic materials may be coated onto or otherwise chemically-bonded to the microbead material, such that the one or more diamagnetic materials have covalent chemical bonds with the microbead material.

In embodiments, the one or more diamagnetic materials may lack covalent chemical bonds with the microbead material but may in some instances interact noncovalently, ionically, or through van der Waals forces with the microbead material. For example, if the microbead material is a polymer material, the one or more diamagnetic materials may lack covalent bounds with the polymer material entirely or the microbead material may lack covalent bonds with just the polymer backbone of the polymer material. In further embodiments, the one or more diamagnetic materials may lack covalent bonds with the water-swellable polymer material entirely or the microbead material may lack covalent bonds with just the polymer backbone of the water-swellable polymer material. In further embodiments, the microbead material may generally surround the one or more diamagnetic materials, yet the one or more diamagnetic materials may be covalently bonded to a functional group of the water-swellable polymer material.

In some embodiments, one or more diamagnetic materials may be incorporated into the microspheres to produce a loaded resin material. A loaded resin material may refer to a microbead material that includes the one or more diamagnetic materials physically disposed within a matrix, network, or pore structure throughout the microsphere material. In some specific embodiments, the loaded resin material may be a graphite-loaded material or a bismuth-loaded material.

In embodiments of incorporating the one or more diamagnetic materials into the microspheres, the microspheres may have a core-shell morphology, where the shell includes the microbead material, and the core, encapsulated by the shell, includes the one or more diamagnetic materials or the loaded resin material. The term "encapsulated" broadly includes embodiments for which the shell or some portion thereof generally surrounds the core. In some specific embodiments, where the microspheres have a core-shell morphology, the shell includes polycarbonate or nylon, and the core includes the loaded resin material. In other embodiments, the one or more diamagnetic materials or the loaded resin material may be the core material encapsulated in a biocompatible resin shell. Examples of the biocompatible resin may include, without limitation, epoxy resins, polyether ether ketone resins, high-density polyethylenes, or combinations thereof. In some embodiments, the biocompatible resin material may be used to separate the one or more diamagnetic materials or the loaded resin material from one or more other functional layers in the microbead. The microspheres having a core-shell morphology may be produced by a microfluidic manufacturing process. In other embodiments, the loaded resin material may be physically disposed within a matrix, network, or pore structure of the microbead material that may or may not have a core within an outer shell.

As stated previously, the diamagnetic material may allow the plurality of microspheres **30** to remain suspended for delivery. The diamagnetic material may reduce interaction or binding of the microspheres with the container **10**. For example, the diamagnetic material may allow the container **10**, described subsequently in more detail, to resist browning or embrittlement from radiation exposure.

Conventional containers used for storing microspheres for embolization may include, for example, glass vials. During storage, the microspheres, which may include radiotherapeutic agents but do not contain a diamagnetic material, can settle out in the conventional containers, thereby coming into direct contact with the conventional container. Over time, as the microspheres for embolization remain in that position within the conventional containers for an extended period of time (for example, greater than one week), the glass of a conventional container may absorb upwards of approximately 5,000 kGy of radiation dose. Consequently, this extended radiation dose may cause the materials of conventional containers to become brittle, crack, flake, discolor, or otherwise integrity compromised.

In contrast, in the presently-disclosed containment systems **100**, when an external magnetic field is applied to the container **10**, microspheres that contain the diamagnetic material are repelled away from the external field. In particular, the plurality of microspheres **30** are repelled from the walls **12**, **14**, **16** of the container **10**. Resultantly, the plurality of microspheres **30** do not settle out in the container **10** or come into direct contact with the container **10**. Rather, the plurality of microspheres **30** may remain suspended within the container **10** without clinging to the container **10**. Additionally, because the plurality of microspheres **30** do not settle out in the container **10** or come into direct contact with the container **10**, the container **10** absorbs a radiation dose less than the dose that would result when the microspheres do contact the container.

Without being bound by theory, the amount of diamagnetic material incorporated into the microspheres, thereby allowing them to be repelled from the container **10**, may depend on various factors, including the weight of the individual microsphere and the distance the microsphere needs to be repelled from the container **10**. In example embodiments, the individual microspheres of the plurality of microspheres **30** may include from about 1% by weight to about 25% by weight, or from about 1% by weight to about 20% by weight, or from about 1% by weight to about 15% by weight, or from about 2% by weight to about 25% by weight, or from about 5% by weight to about 25% by weight, or from about 10% by weight to about 25% by weight diamagnetic material, based on the total weight of the individual microspheres in the plurality of microspheres **30**.

In embodiments, the plurality of microspheres **30** may include one or more drug-loaded microspheres. In some embodiments, the plurality of microspheres **30** may be entirely made up of drug-loaded microspheres, where each microbead also includes a diamagnetic material. In other embodiments, the plurality of microspheres **30** may include a mixture of drug-loaded microspheres and microspheres that include a diamagnetic material.

In embodiments, the drug-loaded microspheres may be microspheres loaded with a therapeutic agent or with a complex of a therapeutic agent and a carrier. Individual drug-loaded microspheres of the plurality of microspheres **30** may include one therapeutic agent or a plurality of therapeutic agents. Collectively, the microspheres of the plurality of microspheres **30** may include some drug-loaded microspheres loaded with one specific therapeutic agent or

a combination of specific therapeutic agents and other microspheres loaded with a different specific therapeutic agent or combination of specific therapeutic agents.

In some embodiments, the therapeutic agent may be a hydrophilic therapeutic agent, a water-soluble therapeutic agent, or a therapeutic agent that has at least some solubility in an aqueous solution. In some embodiments, the therapeutic agent may be a chemotherapeutic agent having at least some efficacy for treating a disease such as cancer. In some embodiments, the therapeutic agent may be a chemotherapeutic agent having at least some efficacy for treating a cancer such as hepatocellular carcinoma, liver cancer, prostate cancer, or breast cancer. The therapeutic agent may have one or more chemical moieties or atomic centers having a positive or negative charge or affinity. Examples of specific therapeutic agents may include, without limitation, doxorubicin, sorafenib, vandetanib, nivolumab, ipilimumab, regorafenib, irinotecan, epirubicin, pirarubicin, 5-fluorouracil, cisplatin, floxuridine, mitomycin C, derivatives of any of the foregoing, prodrugs of any of the foregoing, therapeutically acceptable salts or crystalline forms of any of the foregoing, or combinations of any of the foregoing. Further examples of suitable therapeutic agents include, without limitation, pirarubicin, mitoxantrone, tepotecan, paclitaxel, carboplatin, pemetrexed, penistatin, pertuzumab, trastuzumab, and docetaxel.

In some embodiments, the therapeutic agent may be a radiotherapeutic agent having at least some efficacy for treating a disease such as cancer. In some embodiments, the therapeutic agent may be a radiotherapeutic agent having at least some efficacy for treating a cancer such as hepatocellular carcinoma, liver cancer, prostate cancer, or breast cancer. The radiotherapeutic agent may include a radioisotope such as a beta-gamma emitter that emits sufficient gamma radiation to enable imaging. Examples of specific radiotherapeutic agents include, without limitation, bismuth-213, boron-10, cesium-131, cesium-137, cobalt-60, dysprosium-165, erbium-169, holmium-166, iodine-125, iodine-131, iridium-192, iron-59, lead-212, lutetium-177, molybdenum-99, palladium-103, phosphorus-32, potassium-42, radium-223, rhenium-186, rhenium-188, samarium-153, selenium-75, sodium-24, strontium-89, technetium-99m, thorium-227, xenon-133, ytterbium-169, ytterbium-177, and yttrium-90. Some other examples include actinium-225, astatine-211, bismuth-213, carbon-11, nitrogen-13, oxygen-15, fluorine-18, cobalt-57, copper-64, copper-67, fluorine-18, gallium-67, gallium-68, germanium-68, indium-111, iodine-123, iodine-124, krypton-81m, rubidium-82, strontium-82, and thallium-201. In some specific embodiments, the plurality of microspheres **30** may include drug-loaded microspheres comprising yttrium-90.

In some embodiments, the water-swellable polymer material or some portion thereof generally surrounds the therapeutic agent or the complex including the therapeutic agent. In some embodiments, a water-soluble polymer material shell may encapsulate a core that holds the therapeutic agent or complex. In other embodiments, the therapeutic agent or the complex may be physically disposed within a matrix, network, or pore structure of a water-swellable polymer material that may or may not have a core within an outer shell.

In some embodiments, the therapeutic agent of the drug-loaded microbead may generally surround the microspheres of the microbead material but lack of covalent chemical bonds between the therapeutic agent and the microbead material. Despite lacking covalent chemical bonds, the therapeutic agent and microbead material may have noncovalent intermolecular interactions such as ionic interactions or a van der Waals interaction. In some embodiments, the therapeutic agent of the drug-loaded microbead may generally surround the microbead material and lack covalent chemical bonds to the polymer backbone water-swellable polymer material, yet the therapeutic agent may be chemically bonded to a functional group of the water-swellable polymer material. In some embodiments, the therapeutic agent is not chemically bonded to the water-swellable polymer material at all.

The drug-loaded microspheres may include an amount of therapeutic agent that has a desired therapeutic effect or activity, based on the intended use for the plurality of microspheres **30** and the particular therapeutic agent present in the individual microspheres. The amount of therapeutic agent in the individual drug-loaded microspheres of the plurality of microspheres **30** may be adjusted through particular techniques involved during drug loading, such as loading time, loading temperature, or concentration of therapeutic agent in a loading solution, for example. The amount of therapeutic agent in the individual drug-loaded microspheres of the plurality of microspheres **30** may be adjusted through synthetic techniques involved for synthesizing the microspheres themselves, such as through adjusting polymer molecular weights, degree of hydrogel crosslinking, polymer density, or polymer porosity of the water-swellable polymer material. For example, when doxorubicin is the therapeutic agent, the amount of drug loading in the drug-loaded microspheres may be adjusted with respect to the number of negative charges in the polymer backbone of the water-swellable polymer material. Similarly, when sorafenib is the therapeutic agent, the sorafenib may be embedded within polymeric micelles or liposomes that may be embedded within the microbead structure. In some embodiments, the amount of therapeutic agent in the individual microspheres of the drug-loaded microspheres may be adjusted through choice of the carrier.

In some embodiments, when the therapeutic agent is a radiotherapeutic agent, the radiotherapeutic agent may be loaded into the microspheres by a precipitation method. For example, when yttrium-90 is the therapeutic agent, such precipitation methods may include preparing a solution of soluble yttrium salt (e.g., YCl_3) for which at least a portion of the yttrium is yttrium-90, chemically converting the soluble salt to small precipitates of an insoluble salt such as yttrium phosphate (YPO_4), adding microspheres to solution containing the precipitates, and causing the yttrium phosphate to nucleate onto the surfaces of the beads and, if the microbead is porous, into at least some of the pores. In another example, such precipitation methods may include adding microspheres to a solution of soluble yttrium (e.g., YCl_3) for which at least a portion of the yttrium is yttrium-90, allowing the soluble yttrium to penetrate into the pores of the microspheres, and then converting the soluble yttrium to insoluble yttrium, which may include yttrium phosphate (YPO_4), yttrium sulfate ($Y_2(SO_4)_3$), and yttrium carbonate ($Y_2(CO_3)_3$). In another example, yttrium-90 may be bonded to or coated onto surfaces of the microbead.

In example embodiments, the individual microspheres of the plurality of microspheres **30** may include from about 1% by weight to about 25% by weight, or from about 1% by weight to about 20% by weight, or from about 1% by weight to about 15% by weight, or from about 2% by weight to about 25% by weight, or from about 5% by weight to about 25% by weight, or from about 10% by weight to about 25% by weight therapeutic agent, based on the total weight of the individual microspheres in the plurality of microspheres **30**.

In some embodiments, the drug-loaded microbead may include a complex of a carrier and a therapeutic agent. In the complex, the therapeutic agent may be chemically bonded to the carrier or may be associated with the carrier by a non-covalent means such as encapsulation or a van der Waals interaction. In embodiments, the complex may be embedded within the microbead material. In further embodiments, the complex may be embedded within the water-swellable polymer material. When the complex is embedded within the microbead material, the carrier may be chemically bonded to the microbead material while the therapeutic agent is not chemically bonded to the microbead material. Without intent to be bound by theory, it is believed that when the therapeutic agent is bonded or associated with the carrier but is not chemically bonded to the microbead material, the drug-loaded microspheres of the plurality of microspheres **30** may be less susceptible to shrinking as a result of replacing water molecules with drug molecules during drug loading. Accordingly, the final size distribution of the drug-loaded microspheres may be controlled more readily by selecting appropriate microbead sizes before the therapeutic agent is loaded.

In embodiments in which the drug-loaded microbead includes a complex of the carrier and the therapeutic agent, the carrier may be any pharmaceutically-acceptable compound that can complex with or encapsulate the therapeutic agent. In some embodiments, the carrier may have charged chemical groups or chemical groups with dipole moments that interact with corresponding chemical groups of the therapeutic agent having an opposite charge or opposite dipole moment. If the carrier is a polymeric material, the carrier may be a different material from the water-swellable polymer material. Non-limiting examples of suitable carriers include polysaccharides, liposomes, polymeric micelles, Pluronics, polycaprolactone-b-methoxy-PEG, poly(aspartic acid)-b-PEG, poly(benzyl-L-glutamate)-b-PEG, poly(D,L-lactide)-b-methoxy-PEG, poly(β-benzyl-L-asparate)-b-PEG). Non-limiting examples of polysaccharides include dextrans and dextran sulfates such as dextran sodium sulfate. In one example embodiment, the carrier may include a dextran sodium sulfate having a weight-average molecular weight of from about 40 kDa (kilodalton) to about 500 kDa, or from about 50 kDa to about 300 kDa, or from about 100 kDa to about 300 kDa, or about 100 kDa to about 200 kDa.

In example embodiments, the individual microspheres of the plurality of microspheres **30** may include from about 1% by weight to about 40% by weight, or from about 1% by weight to about 30% by weight, or from about 1% by weight to about 25% by weight, or from about 1% by weight to about 20% by weight, or from about 5% by weight to about 40% by weight, or from about 10% by weight to about 40% by weight, or from about 20% by weight to about 40% by weight carrier, based on the total weight of the individual microbead in the plurality of microspheres **30**.

In example embodiments, the individual microspheres of the plurality of microspheres **30** include water. In example embodiments, the individual microspheres of the plurality of microspheres **30** according to embodiments may have a low water content such as less than 1% by weight, or less than 0.5% by weight, or less than 0.1% by weight, or less than 0.05% (500 ppm) by weight, or less than 0.02% (200 ppm) by weight, or less than 0.01% (100 ppm) by weight, or less than 0.005 (50 ppm) by weight, or less than 0.002% (20 ppm) by weight, or less than 0.001% (10 ppm) by weight water, based on the total weight of the individual microspheres. Without intent to be bound by theory, it is believed that a low water content of the microbead increases the shelf-life and long-term stability of the microbead. Further, it is believed that water contents significantly greater than 1% by weight (such as 2%, 3%, 5%, or 10%, for example) based on the total weight of the microbead, may lead to decomposition or hydrolysis of the therapeutic agent, instability or breaking apart of the water-swellable polymer, or a combination of these, within a few days or even a few hours, such that the microbead cannot be used for embolization procedures, even if the microbead is rehydrated. It is believed that the shelf-life and long-term stability of having water contents significantly greater than 1% by weight are not sufficiently long to ensure viability of the therapeutic agent over the time period from manufacture of the microbead to use of the in an embolization procedure. It is believed that selection of the water-swellable polymer material may correlate with the ability for water to be removed from the microspheres by lyophilization or other drying technique or combination of drying techniques in an amount sufficient to prevent decomposition of the therapeutic agent.

A low water content of the microbead, as previously described, may be attained by drying techniques. In this regard, the microspheres may be dry or nearly dehydrated compositions of the microspheres containing the embedded therapeutic agent or the embedded complex of the therapeutic agent and the carrier. The microspheres may have a powder-like consistency. Accordingly, the microspheres may be made suitable for injection into a subject being treated by rehydrating the microspheres so that the plurality of microspheres **30** may be suitable for embolization. Regardless, the microspheres may be provided in such a form that a physician needs to add only an aqueous solution such as water or physiologically buffered saline solution to the plurality of microspheres **30** to prepare the plurality of microspheres **30** for use in an embolization procedure.

Reference will now be made in detail to embodiments of methods of containing radioactive microspheres. In embodiments, the method of containing radioactive microspheres may include storing a plurality of microspheres comprising a diamagnetic material in a container comprising one or more magnetic fields and whereby the plurality of microspheres contained in the container interact with the one or more magnetic fields of the container **10** in a manner that prevents direct contact of the plurality of microspheres to the container. Storing the plurality of microspheres **30** in the container **10** may further include loading the plurality of microspheres **30** into the container **10** per any suitable manufacturing or shipping process. In some embodiments, the method may further include activating one or more magnetic components of the container **10**, as previously described. In embodiments, activating the one or more magnetic components may include applying an electric current to the container. In embodiments, the magnetic components may be selectively activated by an electronic interaction, such as by a battery and a switch or other suitable activating means. The diamagnetic levitation between the plurality of microspheres **30** and the container **10** may keep the spheres from settling in the container **10** or coming into direct contact with the walls of the container **10**.

The present disclosure includes one or more non-limiting aspects. A first aspect may include a microsphere containment system for storing microspheres including a diamagnetic material, the system comprising: a microsphere container comprising walls that define a containment space in the microsphere container, the walls comprising at least one magnetic component configured to produce a magnetic field within the containment space; wherein microspheres including a diamagnetic material, when stored within the contain-

ment space, interact with the magnetic field within the containment space in a manner that prevents direct contact of the microspheres with the walls of the microsphere container.

A second aspect may include the first aspect, wherein the magnetic component is chosen from permanent magnets, ferromagnetic elements, electromagnets, or combinations thereof.

A third aspect may include any preceding aspect, wherein the magnetic field within the containment space comprises multiple zones having varying magnitudes of magnetic field strength.

A fourth aspect may include any preceding aspect, further comprising microspheres stored within the containment space, the microspheres comprising a diamagnetic material.

A fifth aspect may include the fourth aspect, wherein the diamagnetic material comprises carbon, a diamagnetic metal, or combination thereof.

A sixth aspect may include any of the fourth through fifth aspects, wherein at least a portion of the microspheres have a core-shell morphology.

A seventh aspect may include the sixth aspect, wherein the diamagnetic material is the core of the core-shell morphology.

An eighth aspect may include any of the fourth through seventh aspects, wherein the microspheres further comprise a chemotherapeutic material, a radiotherapeutic material, or both.

A ninth aspect may include any of the fourth through eighth aspects wherein the microspheres comprises yttrium 90.

A tenth aspect may include any of the fourth through ninth aspects, wherein the microsphere container is a syringe barrel.

An eleventh aspect may include a method of containing radioactive microspheres, the method comprising: loading microspheres comprising a diamagnetic material into a microsphere container comprising walls that define a containment space in the microsphere container, the walls comprising at least one magnetic component configured to produce a magnetic field within the containment space; and whereby the microspheres in the microsphere container interact with the magnetic field in a manner that prevents direct contact of the microspheres to the container.

A twelfth aspect may include the eleventh aspect, wherein the diamagnetic material comprises carbon, and a diamagnetic metal, or both.

A thirteenth aspect may include the eleventh through twelfth aspects, wherein at least a portion of the microspheres have a core-shell morphology.

A fourteenth aspect may include the eleventh through thirteenth aspects, wherein the diamagnetic material is the core of the core-shell morphology.

A fifteenth aspect may include the fourteenth aspect, wherein the one or more magnetic components are chosen from permanent magnets, ferromagnetic elements, electromagnets, or combinations.

A sixteenth aspect may include the thirteenth aspect, wherein the magnetic field within the containment space comprise multiple zones having varying magnitudes of magnetic field strength.

A seventeenth aspect may include the eleventh through sixteenth aspects, wherein the magnetic component comprises an electromagnet, the method further comprising applying an electric current to the electromagnet to produce the magnetic field.

An eighteenth aspect may include the eleventh through seventeenth aspects, wherein the microspheres further comprise a chemotherapeutic material, a radiotherapeutic material, or both.

A nineteenth aspect may include the eleventh through eighteenth aspects, wherein the microspheres comprise yttrium 90.

A twentieth aspect may include the eleventh through nineteenth aspects, wherein the microsphere container is a syringe barrel.

For the purposes of describing and defining the present disclosure, it is noted that the term "substantially" is used herein to represent the inherent degree of uncertainty that may be attributed to any quantitative comparison, value, measurement, or other representation. The term "substantially" is used herein also to represent the degree by which a quantitative representation may vary from a stated reference without resulting in a change in the basic function of the subject matter at issue. As such, it is used to represent the inherent degree of uncertainty that may be attributed to any quantitative comparison, value, measurement, or other representation, referring to an arrangement of elements or features that, while in theory would be expected to exhibit exact correspondence or behavior, may in practice embody something slightly less than exact.

While particular embodiments have been illustrated and described herein, it should be understood that various other changes and modifications might be made without departing from the spirit and scope of the claimed subject matter. Moreover, although various aspects of the claimed subject matter have been described herein, such aspects need not be utilized in combination. It is therefore intended that the appended claims cover all such changes and modifications that are within the scope of the claimed subject matter.

The invention claimed is:

1. A microsphere containment system for storing microspheres including a diamagnetic material, the system comprising:

a microsphere container comprising walls that define a containment space in the microsphere container, the walls comprising at least one magnetic component configured to produce a magnetic field within the containment space;

further comprising microspheres stored within the containment space, the microspheres comprising a diamagnetic material, wherein the microspheres including the diamagnetic material, when stored within the containment space, interact with the magnetic field within the containment space in a manner that prevents direct contact of the microspheres with the walls of the microsphere container, wherein the microspheres further comprise a chemotherapeutic material, a radiotherapeutic material, or both.

2. The system of claim **1**, wherein the magnetic component is chosen from permanent magnets, ferromagnetic elements, electromagnets, or combinations thereof.

3. The system of claim **1**, wherein the magnetic field within the containment space comprises multiple zones having varying magnitudes of magnetic field strength.

4. The system of claim **1**, wherein the diamagnetic material comprises carbon, a diamagnetic metal, or combination thereof.

5. The system of claim **1**, wherein at least a portion of the microspheres have a core-shell morphology.

6. The system of claim **5**, wherein the diamagnetic material is the core of the core-shell morphology.

7. The system of claim 1, wherein the microspheres comprises yttrium-90.

8. The system of claim 1, wherein the microsphere container is a syringe barrel.

9. A method of containing radioactive microspheres, the method comprising:

loading microspheres comprising a diamagnetic material into a microsphere container comprising walls that define a containment space in the microsphere container, the walls comprising at least one magnetic component configured to produce a magnetic field within the containment space; and

whereby the microspheres in the microsphere container interact with the magnetic field in a manner that inhibits direct contact of the microspheres to the microsphere container, wherein the microspheres further comprise a chemotherapeutic material, a radiotherapeutic material, or both.

10. The method of claim 9, wherein the diamagnetic material comprises carbon, and a diamagnetic metal, or both.

11. The method of any claim 9, wherein at least a portion of the microspheres have a core-shell morphology.

12. The method of claim 11, wherein the diamagnetic material is the core of the core-shell morphology.

13. The method of claim 12, wherein the at least one magnetic component is chosen from permanent magnets, ferromagnetic elements, electromagnets, or combinations.

14. The method of claim 11, wherein the magnetic field within the containment space comprise multiple zones having varying magnitudes of magnetic field strength.

15. The method of claim 9, wherein the magnetic component comprises an electromagnet, the method further comprising applying an electric current to the electromagnet to produce the magnetic field.

16. The method of claim 9, wherein the microspheres comprise yttrium-90.

17. The method of claim 9, wherein the microsphere container is a syringe barrel.

* * * * *